Automated Characterisation of Keratoconus Cone Shape

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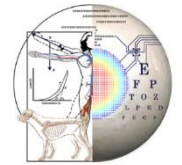

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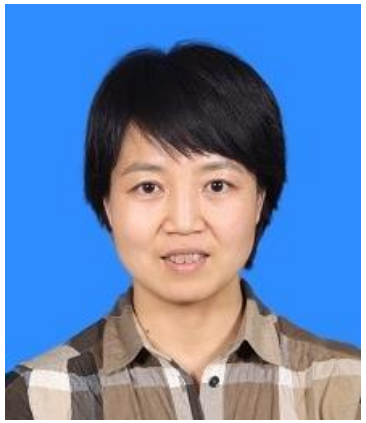
Liverpool group & Research Partners

Ashkan Eliasy
(Liverpool)



Haixian Zhang
(Beijing)

Bernardo Lopes
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Ahmed Abass
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Cynthia Roberts
(Ohio)

Riccardo Vinciguerra
(Milan)

Paolo Vinciguerra
(Milan)

Renato Ambrosio
(Brazil)

Challenges in corneal shape measurement

Since its early developments (1619) until the the advent of corneal topography in late XX's

corneal shape has been described by means of its curvature.

Late 1990's Placido-disk Topography was established as gold-standard for KC assessment

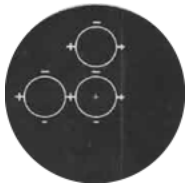
Multiple types of Curvature Maps

Absence of methods to define cone boundaries

Corneal Curvature Measurement History

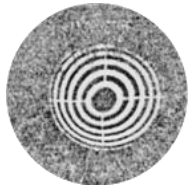
- 1619 - Father Cristoph Scheiner - corneal curvature

- 1851 - Hermann von Helmholtz – keratometer

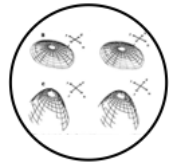


- 1880 - António Plácido – keratoscope

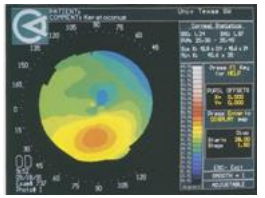
- 1961 - Marc Amsler - forme fruste



- 1984 - Stephen Klyce - Computer-assisted corneal topography



- 1993 - Wilson & Klyce - Standardised color-coded maps



- 1990's - Rabinowitz - KC diagnostic criteria

Axial vs Tangential Curvature Maps

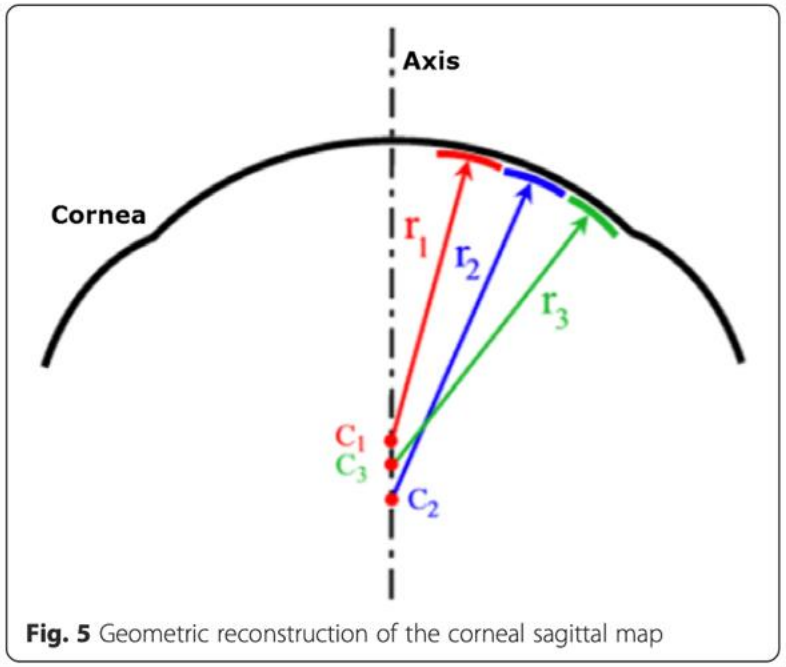


Fig. 5 Geometric reconstruction of the corneal sagittal map

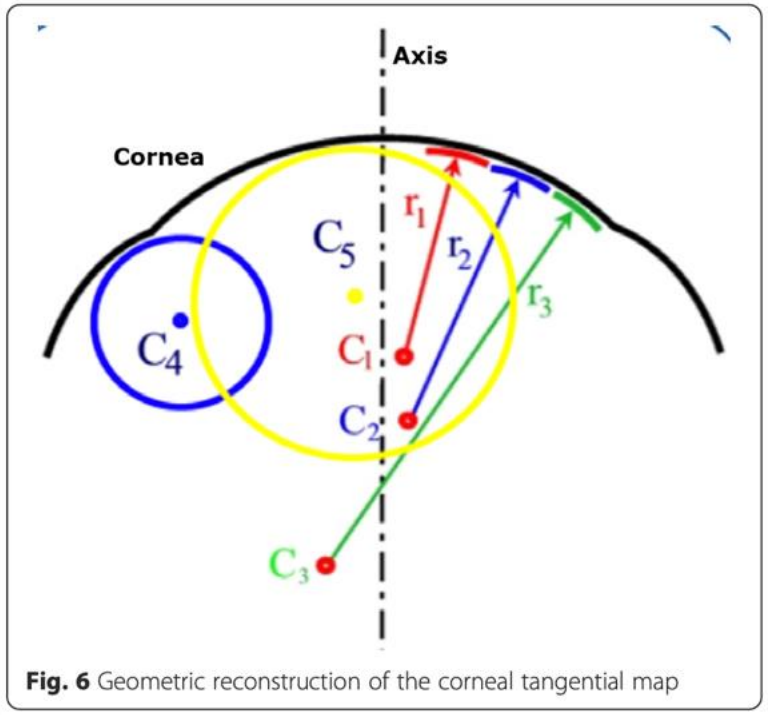
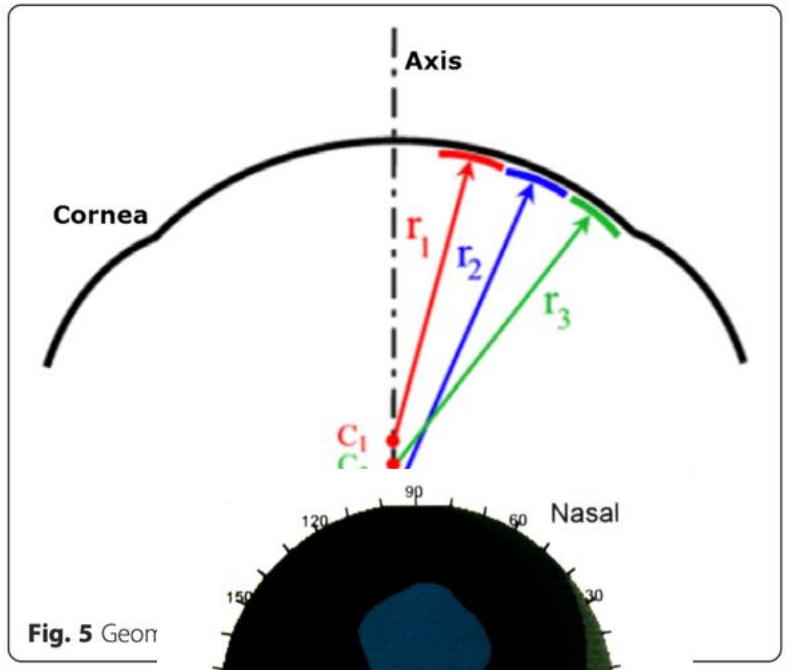
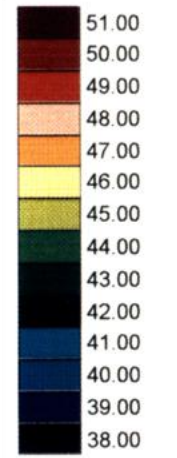


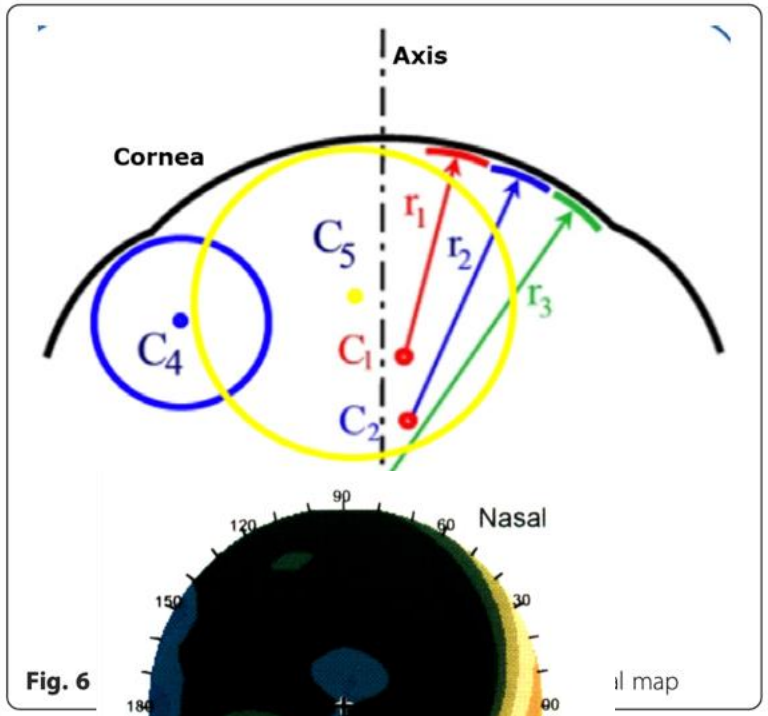
Fig. 6 Geometric reconstruction of the corneal tangential map

Cavas-Martínez et al. Eye and Vision (2016

Axial vs Tangential Curvature Maps





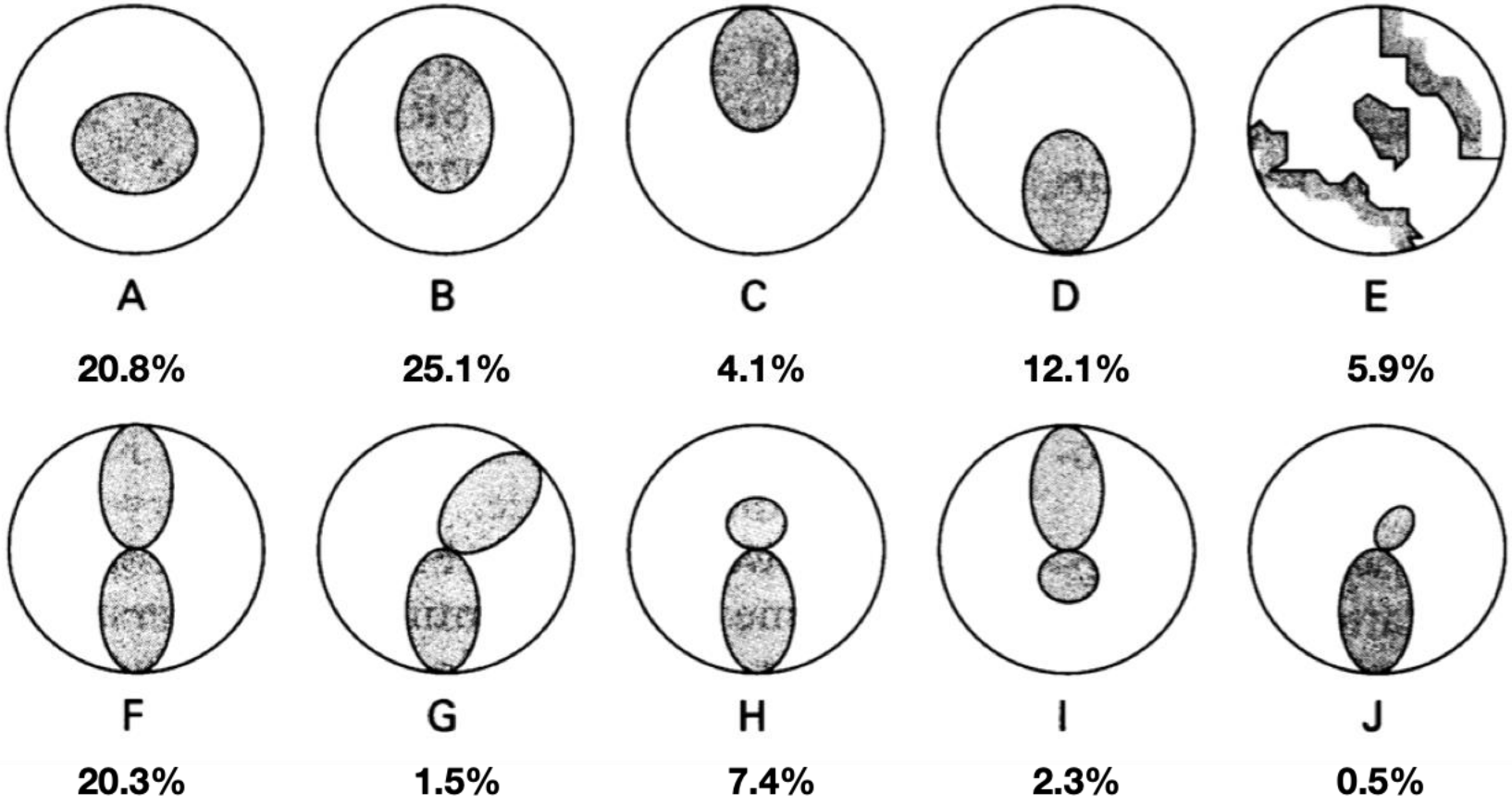


Rabinowitz YS. Am J Ophthalmol. 1996 Dec;122(6):887-9.

Cavas-Martínez et al. Eye and Vision (2016

Corneal Topographic Representation of KC

‼️ One cannot derive cone centre or shape from different curvature patterns

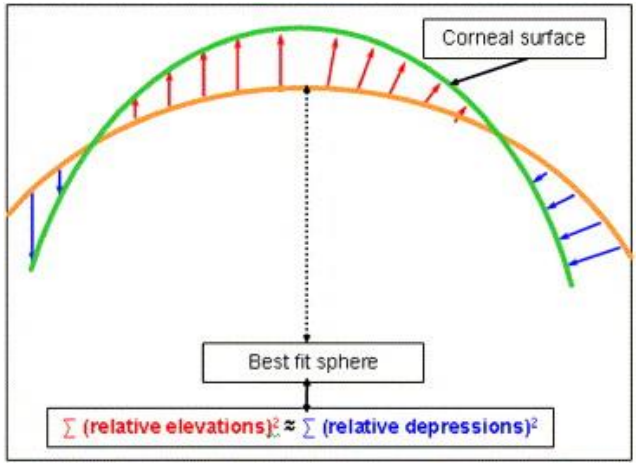


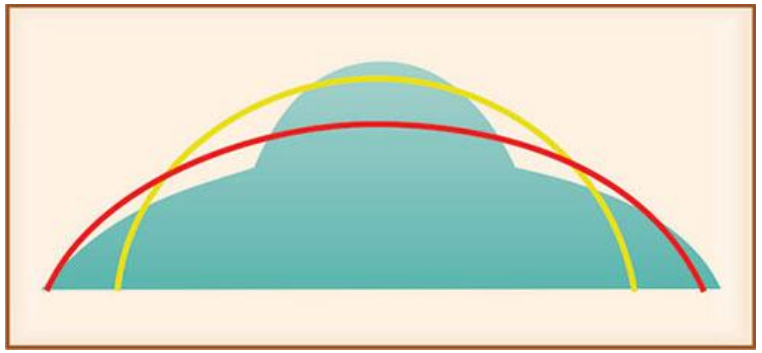
British Journal of Ophthalmology1996;80:610-616

Relative Elevation Maps

Advantages

Cone protrusions more evident





Limitations

High dependance on reference shape
Absence of method to detect boundaries

Corneal Topography in Clinical Practice (Pentacam System): Basics & Clinical Interpretation, 2012

JCRS Volume 32, Issue 8, August 2006, Pages 1281-1287

Aims of Cone Shape Algorithm

1) To Locate Cone Centre

independently of curvature or relative elevation maps

2) To Define Cone Boundaries

with little influence of corneal natural curvature

Locate Cone Centre

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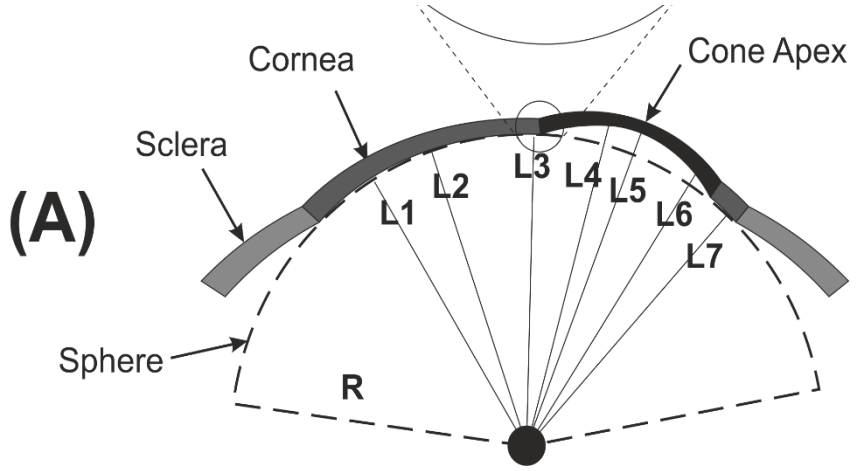
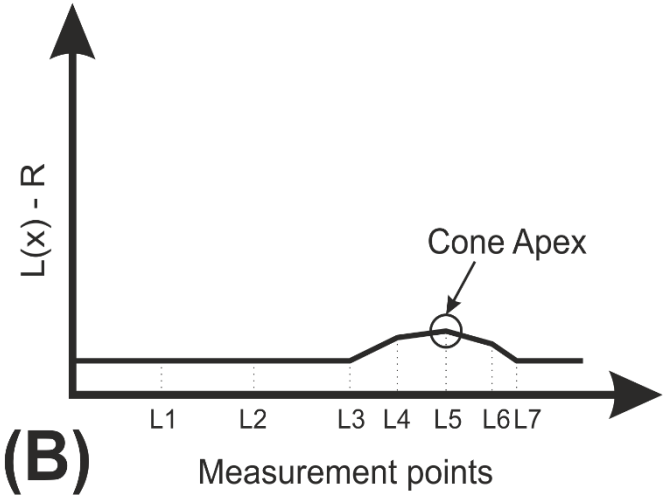
“Neutralisation” of corneal curvature

- Fit each of corneal surfaces to the optimal sphere
- Build radial elevation maps
- Locate the highest point





Define Cone Boundaries

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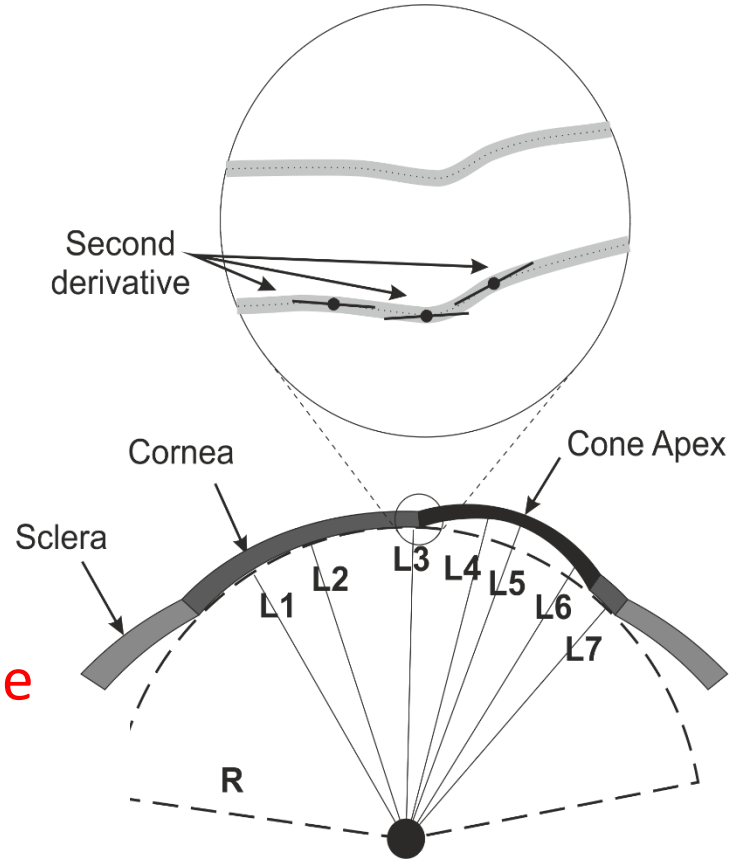
First derivative of the height data
to determine the gradient of the tangent to the surface

Second derivative of height data
to represent the rate of change of this gradient

Change in sign of second derivative
boundaries between Cone and surrounding healthy tissue



Output Example

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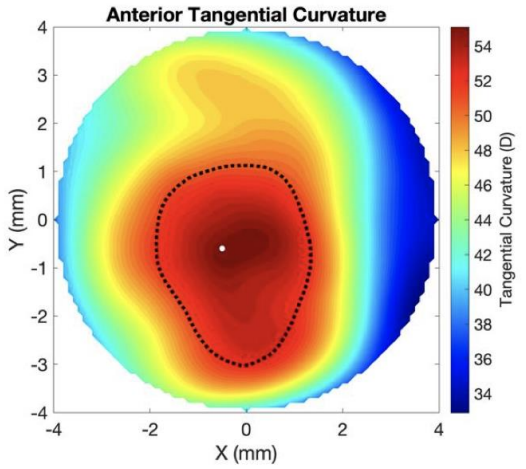
42 yrs Female Patient

Moderate KC

A



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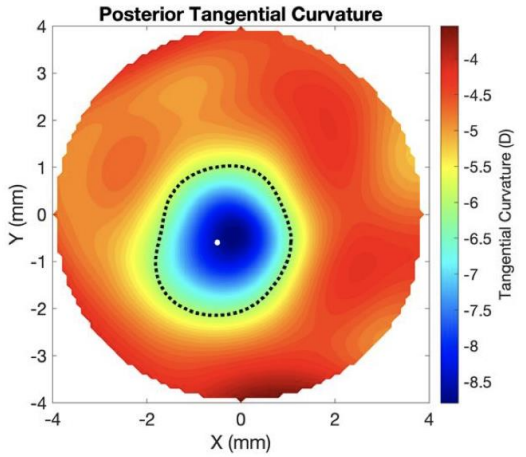

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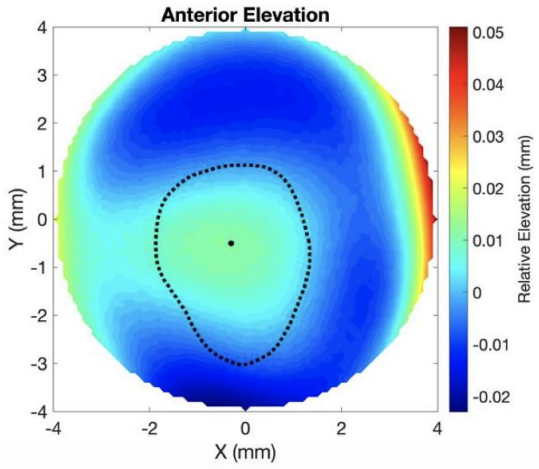

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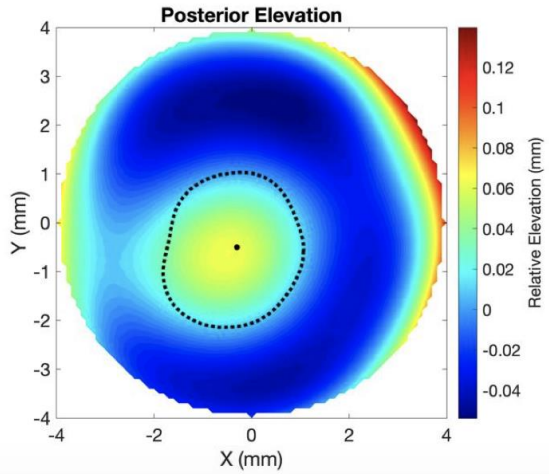

First Publication

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INTERFACE

royalsocietypublishing.org/journal/rsif

Research

Characterization of cone size and centre in keratoconic corneas

Ashkan Eliasy[1], Ahmed Abass[1], Bernardo T. Lopes[1,2,3], Riccardo Vinciguerra[4], Haixia Zhang[5], Paolo Vinciguerra[6,7], Renato Ambrósio Jr[3,8], Cynthia J. Roberts[9] and Ahmed Elsheikh[1,10,11]

Main KC Features

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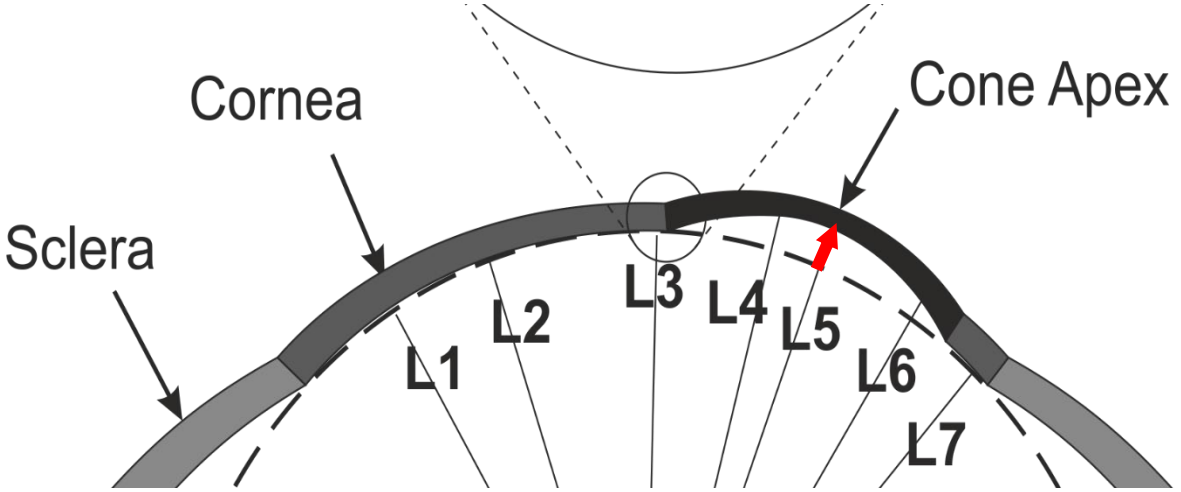
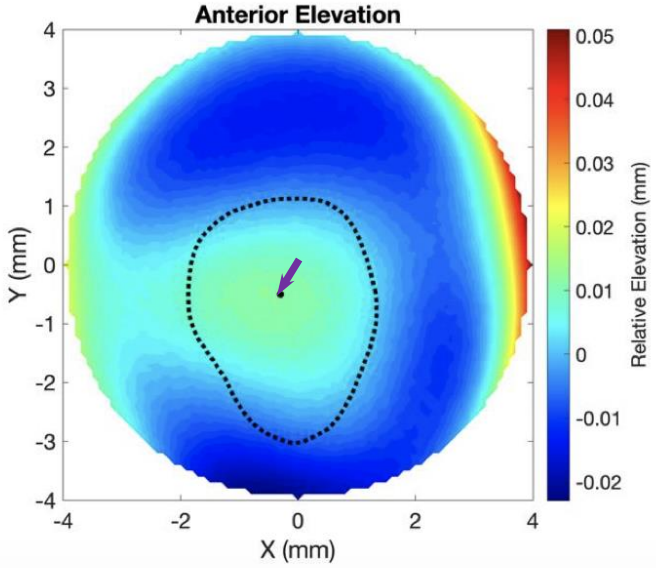
Cone height



Cone area

Cone distance to corneal apex



Cone features with KC severity

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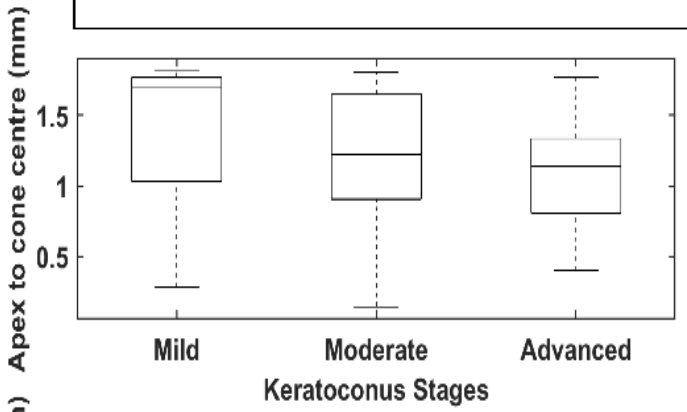
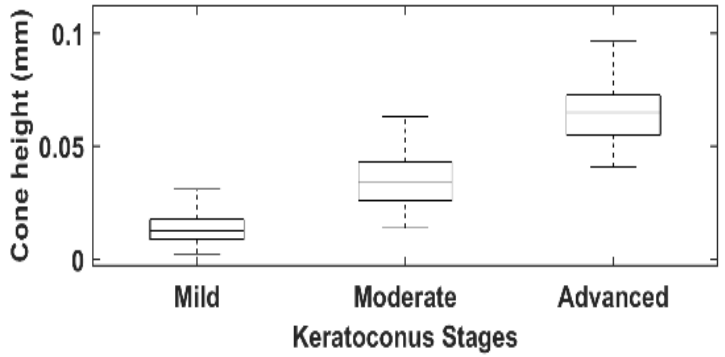
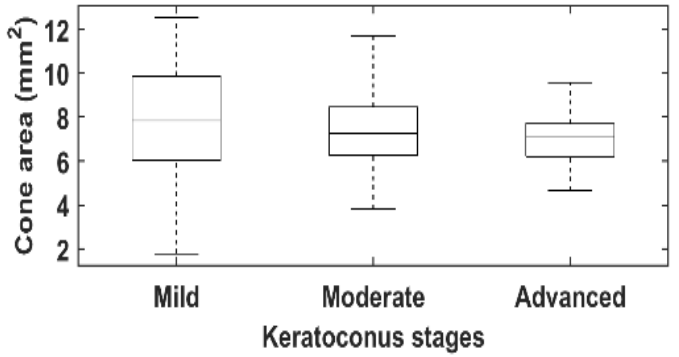
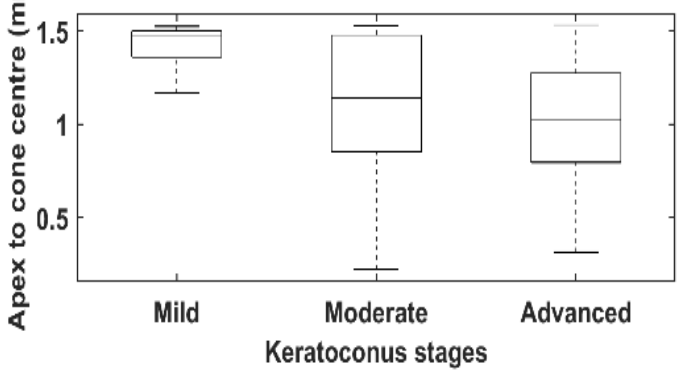
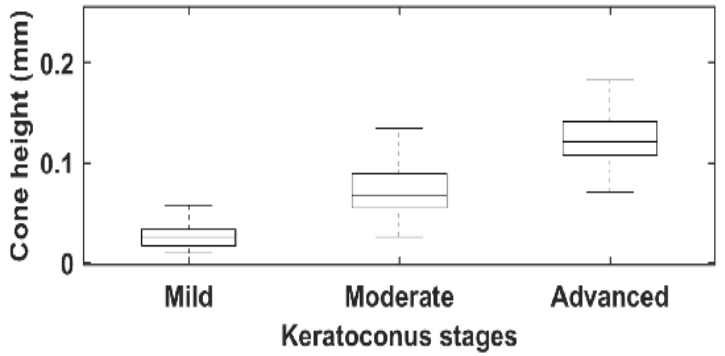
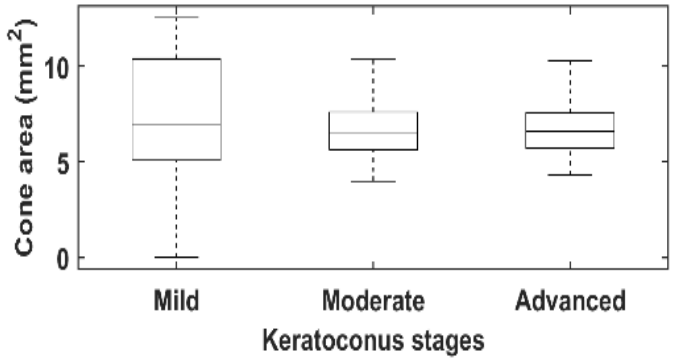
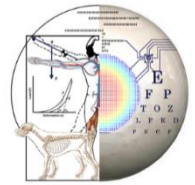
	Distance from cone centre to corneal apex	Cone height	Area of cone
	R= -0.312 (p<0.001)	R= 0.716 (p<0.001)	R= -0.092 (p=0.002)
	Moderate	Strong	Weak
Anterior surface			
Posterior surface			

Clinical Validation



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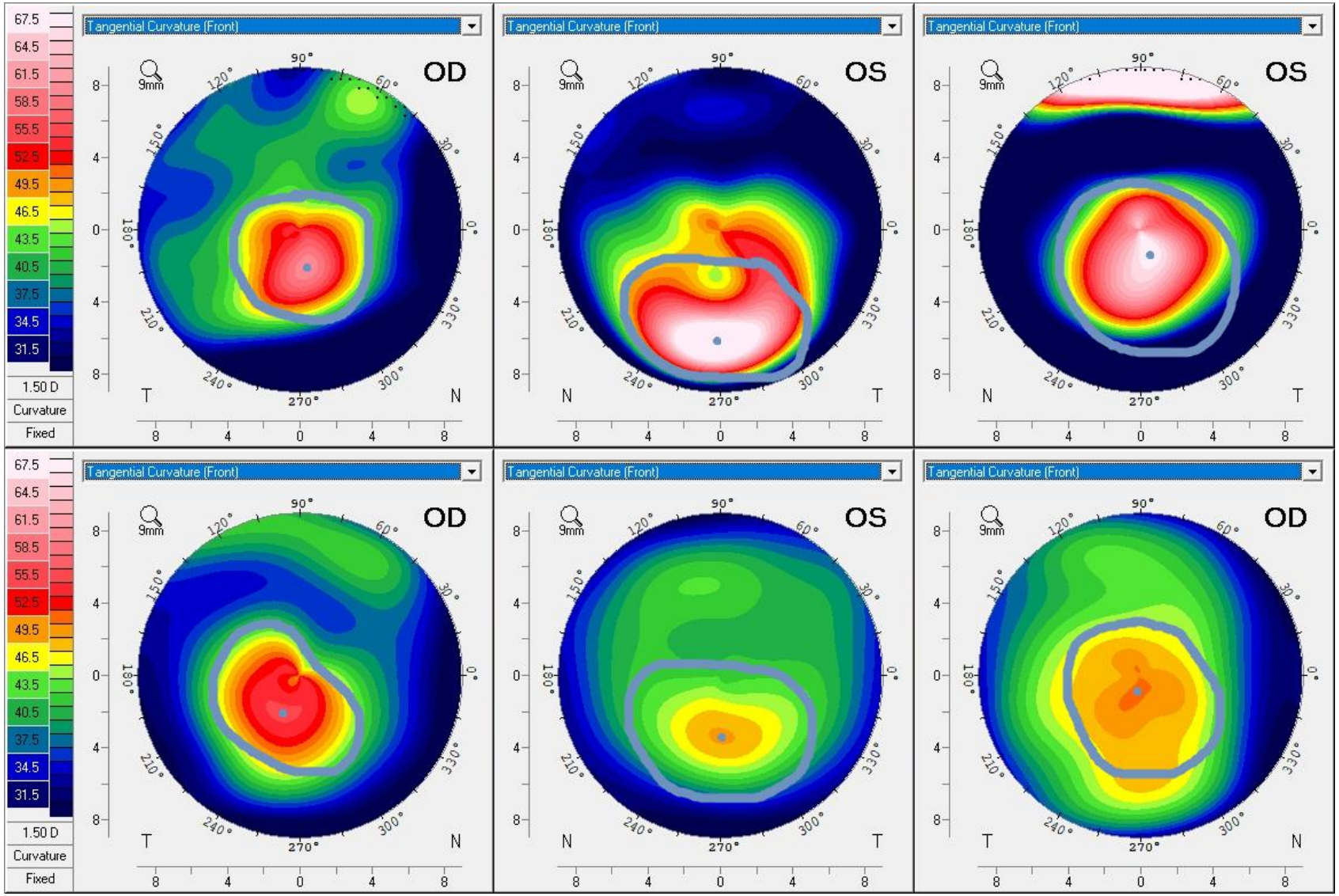
12 Cornea specialists blindly evaluated 6 KC cases

(2 Mild, 2 Moderate and 2 Severe)

Were asked to locate cone centre and boundaries using

Tangential Curvature and Relative Elevation Maps

Clinical Validation



Expert and Algorithm estimates

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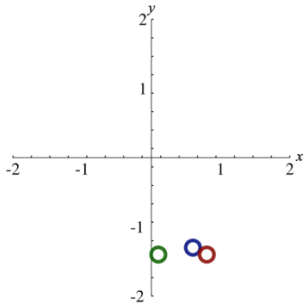
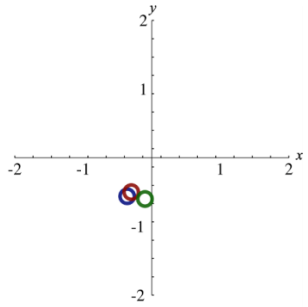
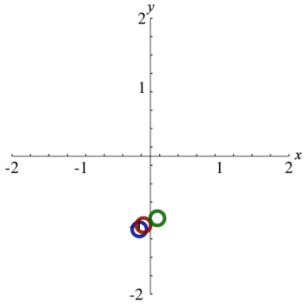
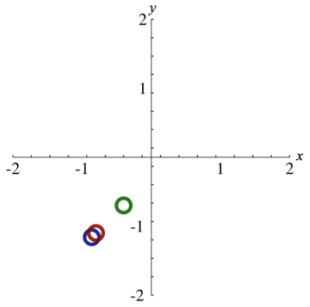
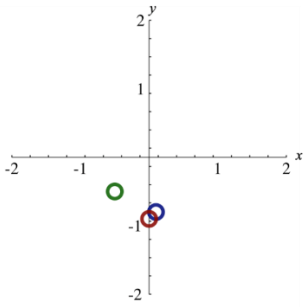
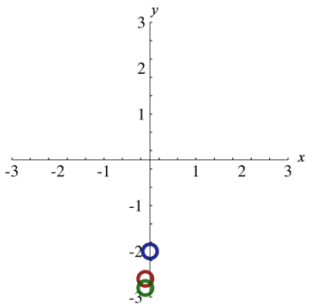
Cone Centre

Expert estimations:

- Relative Elevation Map
- Tangential Curvature Map
- Algorithm

Expert and Algorithm estimates

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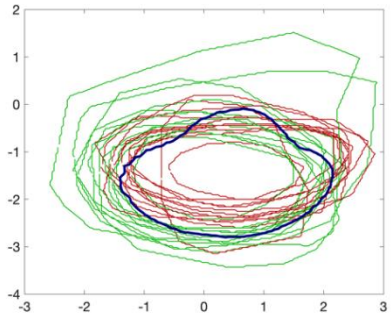
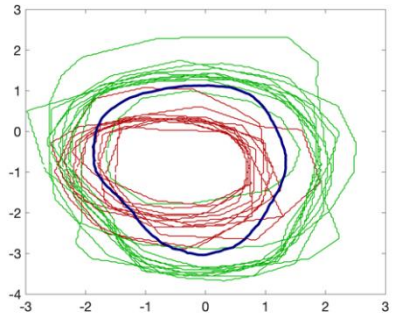
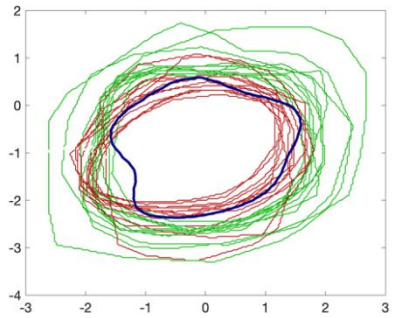
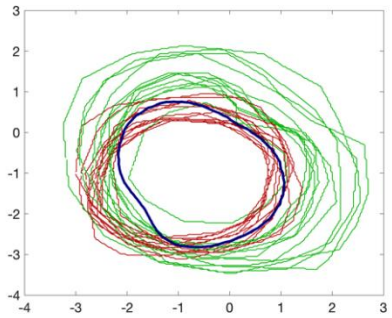
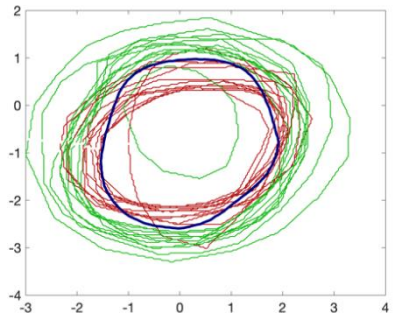
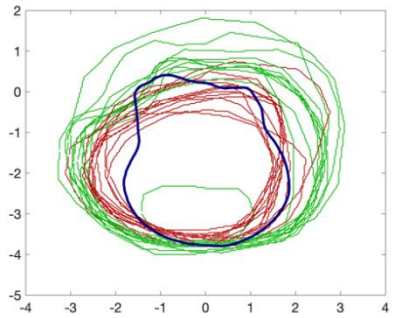
Cone Boundaries

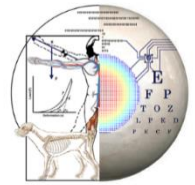
Expert estimations:

— Relative Elevation Map

— Tangential Curvature Map

— Algorithm

Expert and Algorithm estimates



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Expert's estimates

Bias towards map type

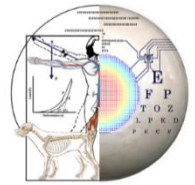
High variability among experts up to 55%

Algorithm estimates

In agreement with clinicians

Independent of map types

Validation of the Algorithm in different populations



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Multicentric Study

Healthy: 706

KC (794)
Mild: 237
Moderate: 396
Severe: 161

Cone centre distributions

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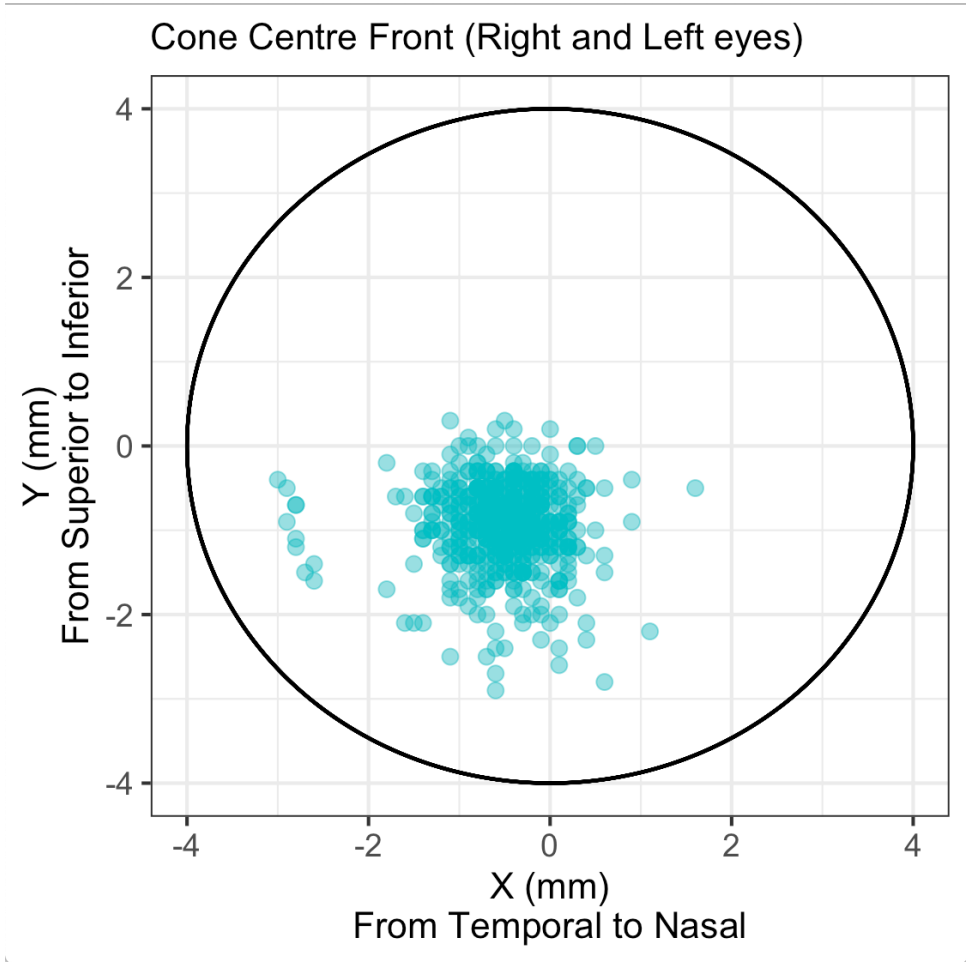
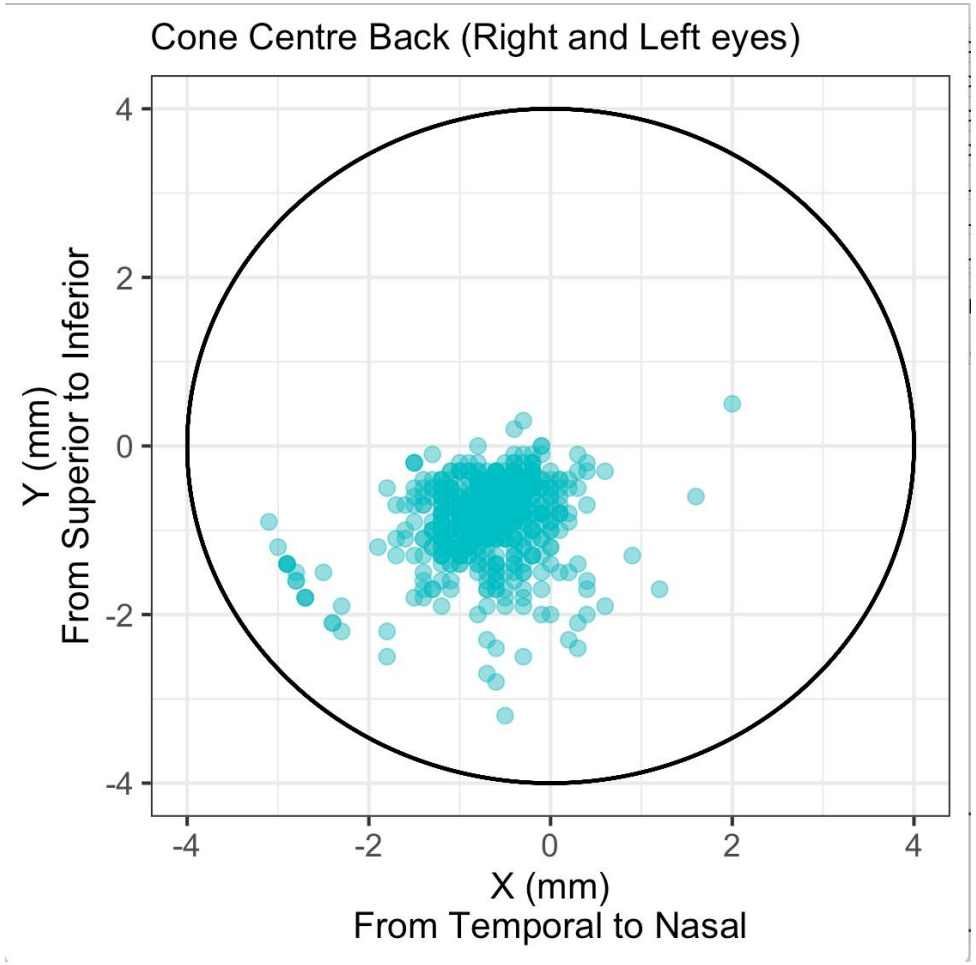
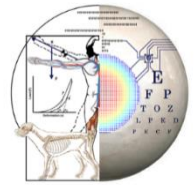
Typical Inferotemporal distribution





Cone Shape algorithm as a diagnostic tool



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Machine learning algorithms were trained to separate healthy and KC based on cone shape features

Train set

80% of Healthy, KC Mild and KC Severe

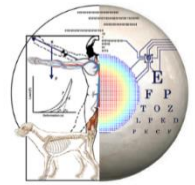
Results expressed with
leave-one-out cross-validation

Test sets

20% of Healthy, KC Mild and KC Severe

KC Moderate

Cone Shape algorithm as a diagnostic tool



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Leave-one-out CV Train (80%) Results:

	TP	TN	FP	FN
Healthy	0	559	6	0
Mild	157	0	0	33
Severe	129	0	0	0

Specificity: 98.9%

Sensitivity: 89.7%

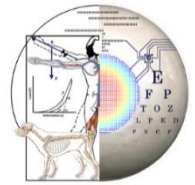
Test (20%) Results:

	TP	TN	FP	FN
Healthy	0	137	4	0
Mild	39	0	0	8
Severe	32	0	0	0

Specificity: 97.2%

Sensitivity: 89.9%

Cone Shape algorithm as a diagnostic tool



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Combined Results (100%):

	TP	TN	FP	FN
Healthy	0	696	10	0
Mild	196	0	0	41
Severe	161	0	0	0

Specificity: 98.6%

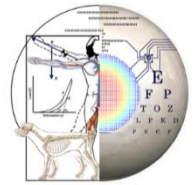
Sensitivity: 89.7%

Independent test results (KC Moderate):

	TP	TN	FP	FN
Moderate	358	0	0	38

Sensitivity: 90.4%

Conclusions



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Automated method for locating centre of KC cone
determining cone height, cone area

Method output is compatible with clinical estimates

Method can be used to distinguish between healthy and keratoconic corneas

To follow:

Method can shed light on KC progression
Both developments to be published soon